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SEDIMENT RETENTION AND WATER QUALITY ENHANCEMENT IN DISTURBED WATERSHEDS

C. M. Cooper[1], F D Shields, Jr[2], S. Testa, III[3] and S S Knight[4]

ABSTRACT

Globally, water quality and quantity issues are alarming. Water quality problems generally result from past and present large-scale land uses. Continuing deterioration of water quality and use/reuse issues place the responsibility on agriculture for water quality improvement. Research on agricultural management practices in the United States shows that production agriculture can use measures that improve water quality. Instream suspended sediments and bedload are, by volume, the largest category of pollutant; sediments also carry many compounds that adhere to them in transport. Thus, reducing sediments must play a major role in improving water quality. Innovative management practices can reduce sediments and nutrients by 70 percent or more. If broadly applied, agricultural management and stream stabilization practices can significantly reduce non-point source contamination and have the extra benefit of improving terrestrial and aquatic habitat.

Key Words: Water quality, Agricultural Management, suspended sediment, Stream stabilization, Aquatic habitat

1 PROBLEM STATEMENT AND OVERVIEW

Quality water is without doubt a limiting substance, not only for humans but for all life. Yet, as human population, activity, and pollution continue to increase, natural sources of readily useable water are declining at an alarming rate. Humans currently divert or regulate more than half of globally available freshwater runoff for their own purposes (Postel et al., 1996), including the use of large dams or diversions on rivers and the widespread creation of other artificial catchments. Additionally, groundwater sources are becoming increasingly used for agricultural and urban purposes at rates that far exceed the natural ability of these reserves to recharge themselves. As a result of human use and disturbance, water quality continues to degrade through alteration of natural physical conditions and from a variety of pollutants including pesticides, excessive nutrients, pathogenic organisms, and the most ubiquitous item, sediment (U.S. EPA, 1994).

These human induced changes to our streams and rivers have serious impacts on both aquatic and terrestrial life. Additionally, artificial linkage of waterways, global transportation and introduction of exotic species have led to unnatural competition, predation, and hybridization between native and non-native species. These impacts pose a major threat to survival of naturally-occurring aquatic organisms and the ecological functions they perform. Recent estimates of vulnerable, imperiled, or extinct aquatic animal species in the United States are approximately 35% of amphibian and fish species, and over 65% of crayfish and unionid mussel species. These risk estimates are two to four times greater than those for similar groups of terrestrial species (Richter et al., 1997).

Modifications to rivers and streams for transport, flood control, or hydropower often result in major alterations of water resources. These activities create changes in temperature, salinity, dissolved gases such as oxygen, and acidity or alkalinity of the water. Industrial water exports may contain toxic metals or chemical compounds, high concentrations of fiber or byproduct materials, and may have asubstantially different temperature from receiving waters.

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Non-point sources may exhibit less profound impacts on receiving waters at a particular location. Because they typically occur over wide areas, their cumulative effects may be more important. Seemingly small changes in nutrient concentrations in receiving waters from urban or agricultural fertilization may have important effects on that water's usability for human consumption and trigger changes in the naturally-occurring biological communities. Major potential sources of non-point contamination include agricultural and urban use of pesticides; livestock waste; wastewater treatment plant export of nutrients, pathogenic bacteria, and biochemical oxygen demand; and land-use activities that increase soil erosion, runoff, and downstream sedimentation.

Sediment production and other agricultural activities affecting water quality of streams in disturbed watersheds are well documented. In general, landscape scale implementation of available technologies to control these sources and impacts remains unrealized although the necessity for such large-scale action to obtain desired goals of water quality, wildlife and land-use protection, and preservation is widely recognized. Attainment of these goals will help provide sustained environmental health and productivity in the agricultural landscape. Thus, we present general recommendations for minimizing or controlling common watershed problems through integrated implementation of beneficial, effective, and cost efficient technologies.

2 RESEARCH LOCATION

Much of the research cited in this article results from projects conducted in the humid south central United States. The National Sedimentation Laboratory is located in one of the highest sediment producing areas in the United States. The upland soils are a fine loess which is highly erodible, and the climate provides 150 cm or more rainfall per year. Major storms occur during periods of minimum vegetative cover, and traditional crops like cotton (*Gossypium hirsutum*) and soybeans (*Glycine max*) leave little residue after harvest. Stream channels are highly erosive with no permanent bed controls. As a result channel erosion is a major concern. Storm flows with 50,000 mg/L of suspended sediment have been measured. Many streams have been straightened and are incised 3 to 5 m into the landscape. Channel widening often follows incision and adds to the huge amount of sediment in transport (Figure 1). Sediment-carrying capacity of channels is reduced where streams flow out of the loess hills into the flood plain of the Mississippi River, creating sedimentation problems. Intensive agriculture in this river alluvium has gradually transformed the landscape as wetlands and buffering riparian zones have been cleared for farming. Fine sediment, moved by erosion processes in the delta, can be a detrimental contaminant in natural lakes and wetlands. It also transports adhering pesticides, metals and nutrients.

3 WATERSHED PRACTICES AND IMPACTS

A watershed scale approach is worthwhile in management planning for non-point contamination problems. While solutions must be conceived on a critical problem area basis, watershed output concentrations or loads are generally accepted measurements of success. Thus, problems and solutions are divided into upland or field areas, transitional or primary transport reaches, and stream corridor segments. A variety of techniques may be employed in the watershed landscape to address problems of soil erosion and water quality protection. Kuhnle et al. (1997) showed evidence that where watershed cultivation was decreased by 14% (from 26% to only 12% of total land use), transport of particles less than 2.0 mm in diameter was reduced by over 60%, and gravel particles (> 2.0 mm) were reduced by nearly 40%. This reduction in cultivation removed sources of sediment, and more importantly, stream energy was reduced as infiltration and runoff decreased. Although reduction in cultivation may not be a practical remedy, other methods of reducing sediment and other contaminants and stream energy (from high intensity runoff) can provide similar effects.

4 BEST MANAGEMENT PRACTICES

Best Management Practices (BMPs) include a variety of methods which minimize transport of pollutants from agricultural land areas. Many types of BMPs are being tested, including tillage options, buffer zones, nutrient management, waste utilization procedures and waste storage structures. Some evaluations of entire watershed BMP implementation are now being published which indicate significant reductions in concentrations and mass transport of pollutants (Edwards et al., 1997a).

4.1 Conservation tillage and cover crops

Suspended or deposited sediment can be quite detrimental to aquatic ecosystems. Rabeni and Smale (1995) found that abundance of herbivorous, benthic insectivorous, and lithophilous spawning fish communities from stream riffles was significantly and negatively correlated with increasing siltation. Cooper (1993) showed that suspended sediments seasonally limited phytoplankton and caused a gradual deterioration of a natural lake ecosystem. Thus, agricultural systems that minimize soil erosion play a substantial role in downstream aquatic productivity potential.

Schepers et al. (1985) illustrated the high correlation between rainfall events, sediment load and nutrient concentrations. Reduced tillage represents a low-cost technique for sediment control, consistently decreasing costs for controlling soil loss in case studies comparing alternative management strategies (Robillard et al., 1980). Razavian (1990) compared runoff and soil loss from a variety of simulated rainfall events in a watershed using conventional till, chisel plow, minimum till, and no-till practices. He found peak runoff and runoff volume were only marginally reduced by the less disruptive tillage practices, but soil loss was consistently reduced by up to more than 80%, even for a 50-year intensity event of 1 hour duration (Figure 2). Five years of data from 16 plots in north Mississippi, USA, showed that no-till cultivation practices reduced soil loss by over 80% for soybean, corn or sorghum production, and by over 70% for cotton (Meyer et al., 1997). No-till soybean production double-cropped with wheat was the least erosive system studied, and use of a Vetch (*Vicia* sp.) cover crop also dramatically reduced runoff. Contoured / terraced row cropping further reduces sediment yields when implemented with no-till techniques, but is not nearly as effective when used alone (McGregor et al., 1997).

Historical trends of fertilization have resulted in nitrogen loading from agricultural lands; forty percent or more of applied nitrogen may be lost through leaching, runoff, volatilization or retention in the soil profile (Hallberg, 1987). Schrieber and Cullum (1998) found no difference in shallow (< 3.04 m) groundwater concentrations of nutrients between conventional and no-till cropping methods for soybeans over a 4 year period, but no-till practices decreased overall nitrogen and phosphorus losses in runoff by as much as a factor of five (largely through the 95-98% decrease in sediment loss). Soluble phosphorus loss was greater in no-till where sediment was unavailable for adsorption to occur. Smith et.al.(1994, 1995) documented that pesticide concentrations in surface runoff were directly linked to time of event after application, emphasizing the importance of weather forecasting technology. Hanks (personal communication) evaluated weed-sensing technology which detected weeds by chlorophyll sensors and found that herbicide applications could be reduced by 50-90 percent.

4.2 Filter and buffer strips and grass hedges

Filter and buffer strips play an important part in newly emerging conservation techniques which will be detailed in an upcoming U.S. Department of Agriculture Natural Resources Conservation Service handbook (USDA-NRCS, In Review). Conventional V- or W-ditches have typically been cut in fully cultivated or plowed fields for drainage purposes, and turnrows denuded of vegetation. Two to seven meter wide grass buffer strips alone provided sediment trapping efficiencies of 50 to 90% (Line, 1991) and 1 to 10 m wide strips reduced sediment from 50 to 99% (Van Dijk et al., 1996). Cotton production areas without and with stiff grass hedges had comparison soil losses of 56 metric tons/hectare and 31 metric tons/hectare using conventional tillage and 3.1 metric tons/hectare and 1.8 metric tons/hectare for no-till plots respectively (McGregor and Dabney, 1993). Buffer strips alone were found inadequate to provide erosion control in a conventional tillage watershed but the integrated use of grass hedges, grassed waterways, and no-till techniques provided comprehensive control of runoff and sediment yield at three watersheds in north Mississippi, USA (Dabney et al., 1997). A vegetated grass filter strip of only 3 to 6 m wide significantly decreased runoff concentrations of iron, potassium, sodium, and zinc associated with poultry manure (Edwards et al., 1997b). Buffer strips of 5 to 10 m in width also can provide an inexpensive method for protecting native plant and animal wildlife, and may provide a bonus benefit of limiting weed interaction between crop and non-crop habitats (Boutin and Jobin, 1998).

4.3 Grass waterways and ditches

Although portions of the runoff from cropped areas may be reduced through increased infiltration, fields need waterways to drain excess water which may be carrying soil and contaminants with it. When used alone, subsurface tile drains previously installed in many fields have the negative potential for quickly moving sediment (Stone and Krishnappan, 1997), nutrients, and pesticides (Kladivko et al., 1991) directly to streams; however, if tile outlets are fitted with small wetland sumps, delivery to streams declines. Grassed waterways and drainage ditches have potential for augmenting water quality improvement. Moore et al. (1999) reported rapid pesticide partitioning to ditch vegetation (61 - 87% of total measured pesticide) just one hour following a simulated storm runoff event.

Upland ponds and reservoirs

Ponds have been constructed throughout landscapes worldwide for water retention, sediment trapping, livestock, recreational and aesthetic use. Although often isolated from waterways, ponds confer many benefits upon neighboring streams by decreasing or eliminating storm runoff transport (Figure 3).

Long term overall sediment trapping efficiency of small impoundments has been reported to range from about 60% to near 100%, but short term trapping efficiency may be more variable, mostly due to changing water residence times (Dendy and Cooper, 1984). Joensuu (1997) compared nearly 100 ponds and noted that ponds could be designed for better sediment retention based upon expected sediment particle size with an associated necessary estimated water detention time. Prediction of sediment retention may often be made for ponds using models for continuous-flow stirred tank reactors in series (Wilson and Barfield, 1984). Yousef et al. (1994) estimated that accumulated sediments would on average need to be removed from detention ponds once every 25 years, but that individual pond sediment accumulation rates were significantly and negatively correlated with increased pond area as a percentage of total drainage area. Watershed reservoirs (4 ha - 20 ha) are commonly used to reduce storm hydrograph flows. Cullum and Cooper (1998) found that watershed reservoirs studied in north Mississippi increased average stage by 105% while maximum stage peaks were reduced by 33%. Average discharge was increased by 48% and peak discharge was decreased by 74% (Chart 1).

Cooper and Knight (1990) found that nitrogen and phosphorus concentrations entering a detention reservoir were highly correlated with storm-related inflow, and that a detention pond was an excellent management tool to buffer and trap these pulses of nutrients, with an overall trapping efficiency of greater than 70% for total phosphorus and greater than 80% for nitrate-nitrogen over a 5-year period. Removal of ammonium-nitrogen can be achieved very rapidly in aerobic water conditions through volatilization and bacterial nitrification (to 99% loss) but more slowly in anaerobic conditions where nitrification does not occur (83% loss in Reddy and Graetz, 1981). In aerobic conditions, ammonia can be converted to nitrate through nitrification; thus, nitrate-nitrogen concentrations may increase with time until the process of denitrification occurs (Reddy and Reddy, 1987; Reddy et al., 1980). Phosphorus removal is mainly sediment related and not dependent on water oxygenation state (Reddy and Graetz, 1981; Johnston et al., 1984). To obtain removal efficiencies above 50% for suspended solids, phosphorus, and heavy metals, Toet et al. (1990) recommended a detention pond volume larger than 200-300 m^3/ha of contributing drainage area based upon models for urban storm water runoff.

For contaminant trapping and removal, Fernandez and Hutchinson (1993) found evidence that undesirable trace element (metals) and organic compound (pesticide) accumulation increased in stormwater detention ponds over time, but in their study, maximum concentrations were below published U.S. chronic exposure levels for aquatic life. Metal concentrations in a sediment retention pond were also found to be higher in sediment pore water than in the overlying surface waters by Wenholz and Crunkilton (1995), but toxicity testing indicated that elevated ammonia concentrations which were associated with the anoxic sediments may have been more detrimental than the observed metals. Cooper, et al. (1995) found primary productivity in Lake Chicot, Arkansas to be sediment limited each year until storm flows with high concentrations of suspended sediments were diverted away from the lake. High suspended sediment concentrations in winter and spring reduced light penetration which effectively minimized phytoplankton productivity (Charts 2 and 3). When suspended sediment levels declined, productivity immediately increased.

4.4 Constructed wetlands

Constructed wetlands show great promise as a bio-technological means of improving water quality of receiving streams. Constructed wetlands have been used as secondary and tertiary treatment systems for wastewater and contaminated runoff from acid and toxic-metal mine effluents, industrial production facilities, animal farming operations, sewage treatment plants, construction sites, and managed land areas susceptible to producing pollutant laden runoff such as golf courses and resort and recreational areas (Figure 4). Designs may be as simple as sandbagging across a first order stream, thus creating a pool and allowing plant succession to begin. More often systems include a deep (> 1 m) aquatic area to receive inflow wastewater, followed by a larger shallow (< 1 m) wetland area containing one or more species of aquatic plant (pond/wetland). Depending on the target contaminant, a wetland/pond/wetland system may be preferable. For concentrated animal wastes, inflows may pass through a large anaerobic lagoon prior to shallow wetland treatment (especially if nutrients are targeted) and are usually diffused at the wetland entrance point to prevent concentrated channel flow. Cooper et al. (1998) measured a suite of parameters in a dairy barn effluent before and after alteration by a constructed wetland (pond/wetland) and postulated that wetlands could be designed for improved trapping of specific target compounds. An introductory examination of many facets concerning wetlands use to treat pollution is contained in U.S. EPA (1993).

A basic design element of constructed wetlands is to create water detention to promote trapping and processing. As this necessarily involves low flow rates, sediments, and other solids contained in the wastewater settle rapidly. While constructed wetland design promotes settling, excessive sedimentation reduces usefulness and decreases the life of the wetland. Solids and decaying plant matter may need to be periodically removed. A constructed wetland that treated cattle waste removed more than 60% of suspended solids over a 3 year period, but these solids were primarily organic particles (Cooper and Testa, 1997).

Constructed wetland treatment systems have the ability to trap and/or process a wide variety of agricultural-related contaminants. Phosphorus and nitrogen have been studied most intensively. A synopsis of constructed wetland use for treating nutrient-laden animal wastes published by the U.S. EPA (1997) contains general design and process information as well as specific case studies. An examination of nutrient transformations in wetland systems is given by Jinescu (1995). In controlled wetland experiments, Moore et al. (1998) found that constructed wetlands quickly partitioned certain pesticides associated with agricultural runoff. When the insecticide chlorpyrifos was injected into a constructed wetland during a simulated storm event, an average of 55% was measured in wetland aquatic macrophytes. Approximately 88% of measured chlorpyrifos was retained within the first 45-54 m of the constructed wetland.

4.5 Drop pipes

Drop pipes (field-scale grade control structures) are common erosion control structures often used to control gully formation. They consist of an earthen embankment and an L-shaped metal pipe to conduct flow from field level to stream level (Figure 5). These structures create water retention sites on the edge of a field, allow sediment deposition at field level where it may be reclaimed, and conduct excessive runoff waters to stream level through an underground pipe, preventing concentrated over bank flow which can result in gully formation. Other situations where these structures are of value are in undulating agricultural landscapes where they drain discontinuous parallel terraces. One study of these structures showed greater than 97% sediment trapping efficiency and a basin life-expectancy of 10 years or more (Mielke, 1985). Design specifications that create permanent or semi-permanent pools at the site of the discharge riser pipe can greatly decrease the amount of sediment and associated nutrients and other contaminants delivered to streams (Schepers et al., 1985).

We conducted three surveys of two uncontrolled gullies and two gullies with drop pipes which were located in an adjacent watershed over a two year period. While the volumes of the uncontrolled gullies expanded 300% and 600%, gullies impounded by drop pipe structures became 3% and 30% smaller due to sediment trapping (Chart 4). The gully which became only 3% smaller was blocked by a drop pipe which experienced partial failure. Use of a perforated riser pipe in the basin coupled with surrounding gravel or expanded polystyrene chips may increase sediment trapping efficiencies in some situations (Engle and Jarrett, 1995).

A study of habitats created by construction of drop pipes identified 100 species of vertebrate animals in these areas, including fish, amphibians, reptiles, mammals and birds (Smiley et al., 1997). Drop pipe structures in Mississippi commonly create suitable wetland habitat for all vertebrate classes, with amphibians being most often encountered, followed by fish, bird, mammal, and reptiles in lesser abundance (Cooper et al., 1997).

4.6 Riparian zone vegetation

Probably the single most important area to be considered when planning methods of controlling sedimentation and water quality of channels and streams is the riparian zone (Figure 6). This vegetated land area which is in direct contact with the waterway can provide numerous beneficial functions, including sediment and nutrient storage, surface and ground water quality enhancement, channel and bank stabilization, stream water temperature control, inputs of organic carbon and structure necessary to aquatic wildlife, and provide streamside corridors for wildlife preservation (Bren, 1993; Lowrance and Vellidis, 1995).

The naturally-occurring forest communities which border waterways have been shown to have important ecological functions, as well as remedial effects for controlling sediment and other pollutants in runoff (Lowrance and Vellidis, 1995). Direct (as with timber harvesting or clearing) or indirect (as with altered hydrology from upstream dams (Bren, 1993)) changes in these communities may have detrimental effects on downstream water resources. A discussion of the benefits associated with riparian zones with guidelines for re-creation and maintenance of riparian zones in disturbed situations is given by Welsch (1992). USDA Forest Service recommends Astreamside zones@ be left intact during timber harvesting activities. Efforts to re-create riparian zones may meet with limited success because of plant competition or harshness of habitat (Shields et al, 1995; Watson et al., 1997), emphasizing the need to protect these areas before they are destroyed or substantially altered.

Although many researchers have concentrated on optimum riparian zone width (Osborne and Kovacic, 1993), qualitative characteristics such as continuity and vegetative cover are also important (Gough, 1988; Rabeni and Smale, 1995). In cases where the riparian zone has been removed or lost due to channel incision or erosion, channel structures may re-create conditions favorable for its re-establishment (Debano and Schmidt, 1990).

Studies in New Zealand revealed that 56-100% of nitrate entering streams in shallow groundwater (0.3 to 1.0 m depth) draining sheep grazing areas was removed by riparian organic soils, despite these soils representing only 12% of the streams' borders (Cooper, 1990). This reduction in nitrate was enabled by the high percentage of groundwater flow passing through the riparian zone before it entered streams. Nitrate, ammonium and phosphate concentrations in groundwater were 16 to 70% less at a wetlands edge than in contributing upland agricultural fields studied by Snyder et al. (1998). Schrieber and Cullum (1998) found that mean nitrate concentration in shallow groundwater of a conventional-till soybean production plot over a 3-year period was 5.98 mg/L but was only 0.29 mg/L in a forested riparian zone 61 m down slope of the agricultural field. Their study also indicated that no-till practices may promote movement of nutrients in groundwater, emphasizing the importance of maintaining the riparian zone in addition to implementing conservation tillage practices.

Riparian zones form a critical habitat for many living species which rely on their presence for survival (Lowrance et al., 1985; Decamps et al., 1987; Naiman and Decamps, 1990). Other species use these areas for food, water, shelter, reproduction and migration. Riparian zones may also harbor many insects that are beneficial to agriculture (Lowrance et al., 1985)

5 CHANNEL PRACTICES AND THEIR IMPACTS

5.1 Channel design

Inappropriate channel design can trigger widespread instability involving headward migration of knickpoints, lowering channel bed elevation, and triggering rapid channel widening. Sediments liberated by these processes impact water quality downstream and may block channels, diverting flow overbank (Simon, 1998). Case studies of accelerated channel erosion following channel modifications are provided by Brookes (1988). Disturbed channels may be rehabilitated using a variety of measures (Brookes and Shields, 1996) including reconstructing the channel with a more sinuous alignment (and thus more gradual bed slope), a wider bed (thus reducing unit stream power), increased woody vegetation and woody debris densities (Shields and Cooper, this volume), and structural bank protection and grade controls. Such measures must be carefully designed with consideration of downstream impacts because treatment of a short reach or bank segment may simply transfer an erosion or deposition problem to downstream location. Effects of channel rehabilitation may diminish downstream due to in-channel storage. For example, using simulation techniques, Bingner (1998) found that a comprehensive project involving grade control structures and bank protection reduced total sediment load as much as 237% from tributary basins but only 15% at the mouth of a 21.3 km^2 watershed.

The effects of channel erosion and its control on water quality are dependent on the quality of sediments liberated by the erosion. In many cases, these sediments may be free of such pollutants, but certain compounds like chlorinated hydrocarbons and those containing heavy metals may be persistent within the soil matrix for many decades (Knight and Cooper, 1991). Channel designs which promote the growth of aquatic vegetation could significantly aid in nitrate removal; stream nitrate concentrations have been shown significantly lower in areas with high plant biomass (Cooper, 1990).

The importance of maintaining or re-creating natural channel attributes can be especially seen when stream organisms are studied. Aquatic macroinvertebrates recovered rapidly from severe (18 and 12 year return interval) flood events in streams with intact abundant refugia, including organic debris dams and accumulations, deep interstitial habitat, and first order tributaries (Angradi, 1997). Stream channels damaged by incision and the attendant erosion and sedimentation generally support inferior fisheries than comparable less degraded streams (Shields et al. 1994).

5.2 Bank protection

Up to 85% of sediments emanating from disturbed watersheds may be produced by bed and bank erosion (Grissinger et al., 1991). Thus, protection of banks may reduce downstream sediment loads. In some landscapes, channel and gully boundaries may contribute as much particulate phosphorus as point sources or artificial fertilizers (Wallbrink et al, 1996).

Use of plant materials alone and in combination with various structures for streambank erosion control is gaining popularity. When banks are stabilized, natural vegetation often invades the riparian zone, leading to restoration of the water quality and ecological functions of these areas. Design manuals such as Natural Resources Conservation Service (1996) are helpful although many basic issues remain to be addressed (Shields and Cooper, this volume). Low-cost measures which can withstand extreme hydraulic forces during floods while plant materials are becoming established are needed. One approach that holds promise is the use of large (~15 to 30 cm diameter) willow (Salix sp.) cuttings (Watson et al., 1997), although success will be limited if designers do not consider site constraints such as moisture and soil texture (Pezeshki et al., 1998).

5.3 Grade controls

A variety of channel structure types may be placed in different reaches of a waterway, with varied effects on the stream transport of sediments. Debano and Schmidt (1990) found that small check structures in upland headwaters help control sediment loads. This process re-fills these small stream channels with sediment promoting increased bank soil retention of water for development of riparian vegetation and a return of the stream to perennial or near-perennial flow. They also reported that larger erosion control structures, or grade control structures, serve to control stream incision and degradation, stabilize intermediate reaches of streambed, store excess sediment, and promote riparian vegetation development.

Smaller grade control structures have been shown to provide beneficial habitat in disturbed stream systems (Cooper and Knight, 1987). Where feasible, they are preferred over larger controls. A series of smaller structures may allow fish passage and cost less than a single large structure. Introduced rock used for these grade control structures and related bank protection has also been shown to provide beneficial habitat for stream invertebrates (Cooper, et al. 1993). Invertebrate communities on these structures were diverse and formed a major dietary base for local fish.

5.4 Lakes and large reservoirs

Debano and Schmidt (1990) caution that creation of large flood protection or water storagè structures may create positive or negative effects dependent on local stream dynamics and channel morphology. Large retention structures may pool vast amounts of nutrient-rich deposited sediment upstream of the dam and at the delta where the stream enters the reservoir which may be beneficial to riparian vegetation, but may pose a problem when the basin is filled or decomissioned. Excessive sediment accumulation rates in lakes and reservoirs is a global phenomenon threatening the functioning of these water bodies (Ritchie et al. 1986). Due to the absence of sediments which settle in the basin, streams downstream of reservoirs may degrade or widen which may have damaging side-effects.

Lake and reservoir management should also consider the sustenance of aquatic vegetation, as these plants may directly (through uptake) and indirectly (through oxidation and production of humic compounds [Christensen et al., 1997]) trap significant amounts of nutrients and metals.

6 SUMMARY AND CONCLUSIONS

The practices described above may be employed at isolated locations within the landscape to correct problems at a given site (for example, gully initiation within a particular field). However, to produce significant changes in non-point source loadings, a coordinated project involving widespread application of a suite of these practices across the watershed is required. Since non-point sources are diffuse, control strategies must also be applied in a spatially extensive fashion, and not at a few selected locations. For example, a given watershed plan might include grassed waterways within fields, constructed wetlands near animal waste sources, and buffer zones of trees on stream and ditch margins. Project design must integrate erosion control and agricultural production goals in a way that considers conditions in all seasons of the annual cycle. Ecological benefits tend to increase in a nonlinear fashion with the spatial extent and dispersion of area treated.

In agricultural production, attention is focused on areas under cultivation or pasture, with little attention given to border areas such as ditches, ponds, field edges, and stream banks. Farm plans which incorporate the practices described above emphasize management of these border areas for their ability to retain and process pollutants. Complete stewardship of the landscape blends concepts for soil and water management, preserving soil productivity and downstream water quality, and habitat for future generations.

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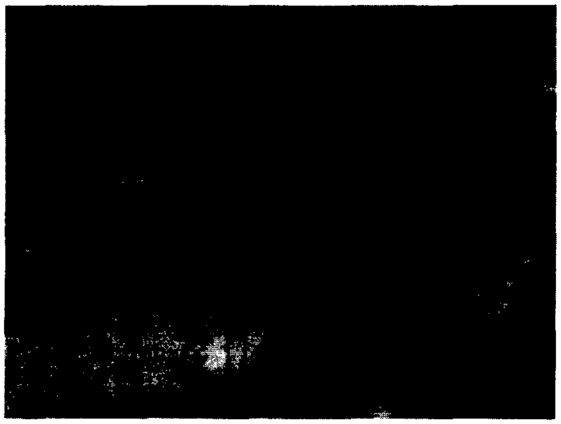

Fig.1. Incision processes degrade streams, cause massive sediment transport due to bed and bank erosion, and promote gully formation.

Fig.2. With no-till farming, a new crop emerges from previous crop stubble. Soil erosion is minimized, as with other best management practices.

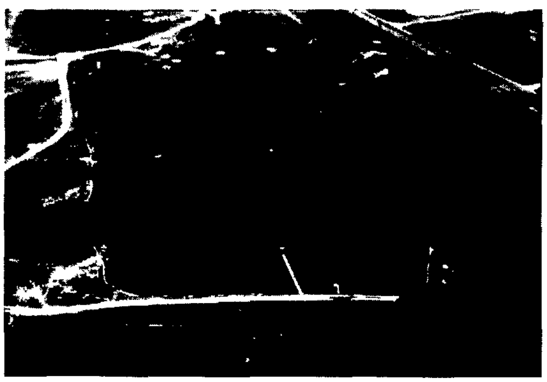

Fig.3. Upland ponds and reservoirs provide onsite trapping of eroded sediment, and trap and process nutrients, metals and pesticides.

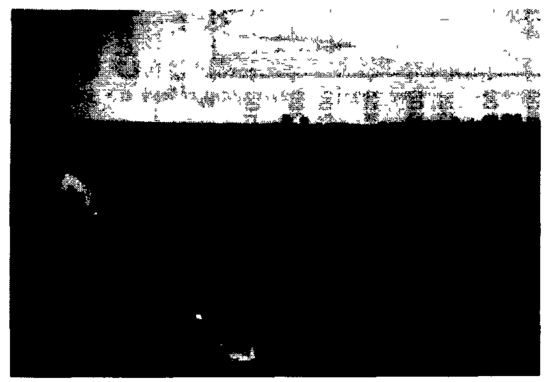

Fig.4. Constructed wetlands create wildlife habitat in addition to treating water before it enters streams or rivers.

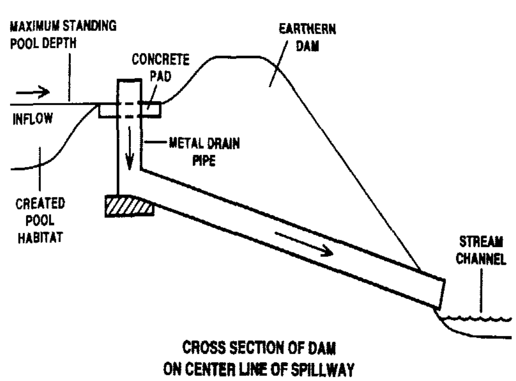

Fig.5. A drop pipe structure, designed as in this schematic, can remedy gullies by removing over-bank flow.

Fig.6. Perhaps most important of all, the riparian zone contacting a receiving stream plays a vital role in water quality enhancement and wildlife ecology

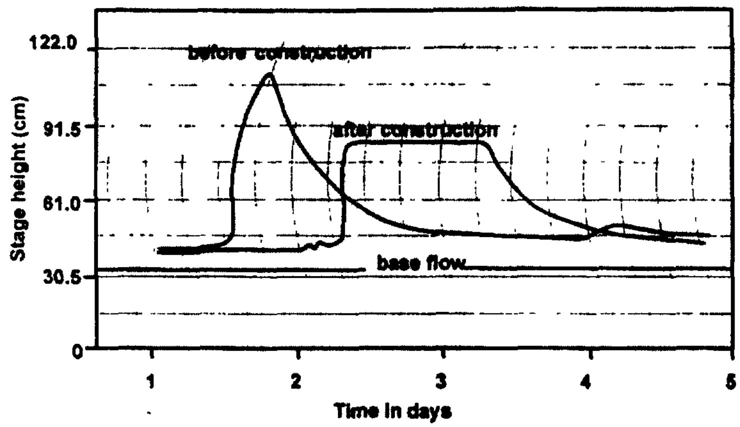

Chart 1. Stage response to comparable rainfall events before and after construction of Watershed Lake Number 2 in upper Otoucalofa Creek, Mississippi (USA).

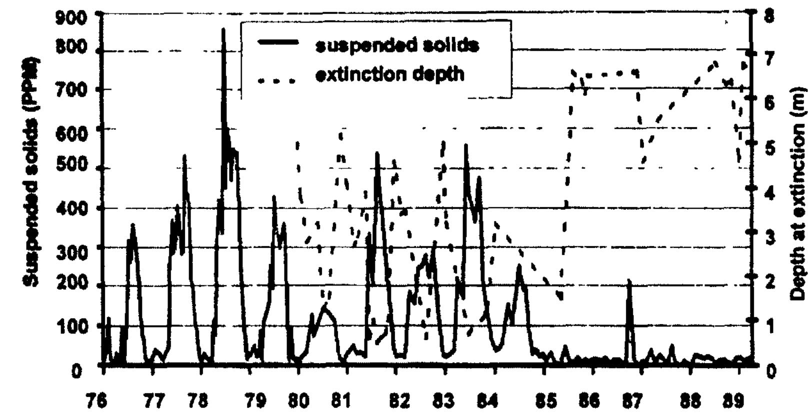

Chart 2. Suspended solids and depth of light extinction in Lake Chicot, Arkansas (USA) from 1976-1989.

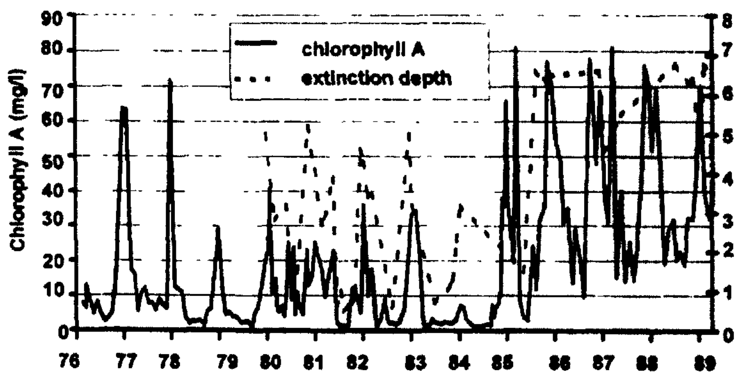

Chart 3. Chlorophyll A and depth of light extinction in Lake Chicot, Arkansas (USA) from 1976-1989.

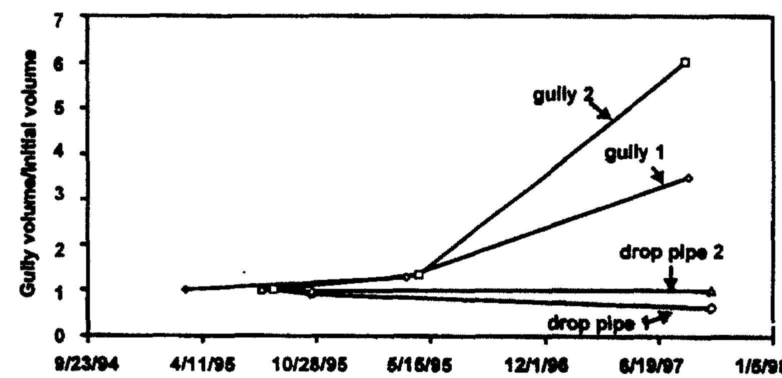

Chart 4. Gully volume over time as compared to initial gully volume in untreated gullies Vs. gullies treated with drop pipes in north Mississippi (USA).